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SUMMER HEAT GAIN CONTROL IN PASSIVE SOLAR HEATED BUILDINGS: FIXED HORIZONTAL OVERHANGS*

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ABSTRACT

An aspect of passive cooling relates to cooling load reduction by the use of solar controls. When there is a substantial winter heating requirement, and when the winter heating needs are met in part by a passive solar heating system, then the potential aggravation of summer cooling loads by the heating system is an important design issue. A traditional solution is the use of a fixed, horizontal shading overhang. The purpose of the present paper is to outline an approach to quantitative design rules for the sizing of a shading overhang to minimize total annual space conditioning energy needs.

1. INTRODUCTION

In climates with appreciable winter heating loads, passive solar heating systems can supply a substantial fraction of a building's heating energy requirement. Much information exists on the performance of such systems, and quantitative design procedures are available to assure their effectiveness.[1] Relatively little information, on the other hand, exists regarding the potential summer overheating problems associated with these systems. The need is for a balanced design in which excessive solar gains are prevented in the summer without seriously compromising the winter heating performance. The most desirable overheating controls are those implicit in the building design and strictly passive in their operation. Additional active control measures that require seasonal or daily operation may be needed as well. A rational design strategy would be to incorporate overheating control measures in a rank order, beginning with strictly passive ones, and adding active measures to whatever extent is required. An objective of research, then, is to provide quantitative information to guide this design process.

Several categories of tools are needed for the development of a balanced design. First are rules of thumb that can be applied very early in the design process. The rules of thumb give guidance concerning preferred sizes or configurations of building elements, for example, the optimum amount and placement of mass and insulation. Second are estimation methods that evaluate the overall performance of a design in terms of, for example, the annual space conditioning energy requirement of the building. Such estimation methods must be simple and fast so that they can be routinely applied to evaluate the overall energy consequences of various design options under consideration. Third are analysis tools that provide detailed information about energy consumption and comfort conditions. This final level of analysis may be relatively expensive and time consuming and thus may be done only once or twice at an advanced stage in the design process to confirm earlier estimates and to guide "fine tuning" of the design. The exact nature and level of sophistication of each of these design tools will depend on the size and type of design project in question, but, taking the example of single-family residential, small commercial, or light industrial buildings, the categories of needed design tools are closely paralleled by the design tools developed strictly for winter heating applications.[1] These are (1) the rules of thumb concerning glazing area, mass, orientation, and other specific building features; (2) the load collector ratio (LCR) method for estimating the annual auxiliary heating energy requirement; and (3) the solar load ratio (SLR) method for estimating the auxiliary heat month by month, and the diurnal capacity calculation for estimating diurnal temperature swings. Comparable design tools that address the issues of balanced design are under development.

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The present paper examines just one design issue: the fixed, horizontal overhang. This traditional, strictly passive solar control device is very compelling in its simplicity of concept: direct low-angle winter sunlight passes below the overhang to enter the building, but direct high-angle summer sunlight is blocked. That the incorporation of an overhang is a thermal design problem at all is because the heating and cooling functions cannot be made completely compatible, that is, full summer shading necessarily implies partial fall and spring shading and the consequent interference with solar heating during these seasons. The design problem, then, is to determine the overhang configuration in which the winter heating and summer shading effects are balanced in such a way as to optimize some aspect of the overall performance. It has been long recognized that a quantitative optimization of this sort is the preferred basis of a design solution, and initial steps have been taken toward providing such a solution.[2] But the overhang sizing tools used most widely are based only on the geometry of sun angles: if a designer can specify how many days the south windows are to be completely shaded and how many days they are to be completely illuminated, then simple tools are available to determine the overhang configuration.[3] The parameters that determine this type of overhang solution are the latitude of the site and the designer's guess as to the appropriate number of shaded and illuminated days. Of those, the only one that can be simply known is the latitude. Unfortunately, the optimum overhang configuration for a given application is so weakly correlated with the latitude that this parameter is not useful by itself in sizing overhangs.

2. THE ANALYSIS

The approach taken here to evaluate the performance of shading overhangs is to examine the space conditioning energy requirement of a passive solar heated building, including the energy inputs to the auxiliary heating and cooling equipment. This may be expressed as

$$Q = Q_h/COP_h + Q_c/COP_c \qquad (1)$$

where Q_h and Q_c are the heating and cooling loads, respectively, and COP_h and COP_c are the average coefficients of performance of the auxiliary heating and cooling systems, respectively. The idea of the analysis is to determine the most favorable solar aperture and overhang configurations, not necessarily to evaluate the actual energy consumption. Therefore, only the relative coefficient of performance between the auxiliary heating and cooling systems is relevant, and it is sufficient to calculate the quantity

$$Q' = Q_h + Q_c/COP \quad , \qquad (2)$$

where $Q' = Q \times COP_h$ and $COP = COP_c/COP_h$ is the coefficient of performance of the cooling system relative to the auxiliary heating system.

Finally, it is convenient to express the result as a relative energy savings due to the presence of an overhang, that is, the energy requirement of the building with no overhang less the energy requirement with an overhang. This energy savings is proportional to the quantity $\Delta Q' = Q'_o - Q'$ where Q'_o is Q' for a building with no overhang. In other words,

$$\Delta Q' = Q_h^o - Q_h + (Q_c^o - Q_c)/COP \quad , \qquad (3)$$

or

$$\Delta Q' = \Delta Q_h + \Delta Q_c/COP \quad , \qquad (4)$$

where ΔQ_h and ΔQ_c are the heating and cooling loads, respectively, without an overhang, less the corresponding quantities with an overhang. Of course, ΔQ_h is negative and ΔQ_c is positive (because the overhang reduces solar gains and interferes with passive solar heating), so that Eq. 4 is an algebraic expression of the trade-off between winter heating and summer shading in the building's energy performance.

The relative COP, in general terms, is the cost of heating relative to cooling, either in terms of energy consumption at the point of use as originally defined, or in other terms as deemed appropriate to the design solution sought. For example, COP could be regarded as the cost of heating relative to cooling in terms of primary fuel consumption, dollar cost of the fuel consumed at the point of use, or even subjective measures of the desired design balance such as the inconvenience or discomfort of underheating relative to undercooling in cases when comfort conditions are not regulated by strict thermostatic control. In any case, COP is a parametric expression of the relative importance of heating and cooling in the design solution that must be supplied by the designer along with the other relevant parameters, such as the latitude of the site and parameters concerning the climate and building characteristics.

The overhang configuration in question is illustrated in Fig. 1. It is assumed that the overhang extends sufficiently beyond the east-west limits of the window that edge effects in the morning and afternoon are negligible. The distance X is the overhang, Y is the separation, and H is the window

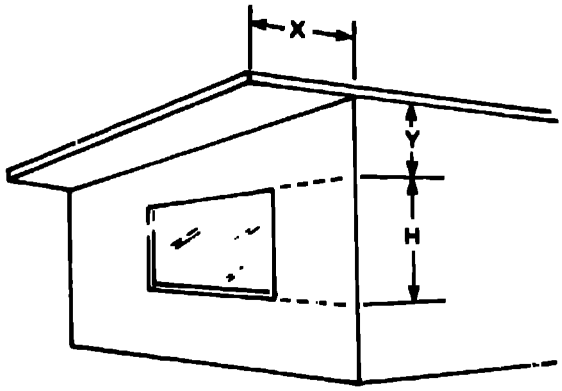

Fig. 1. Overhang geometry.

height. The shading performance of the overhang is determined by just two parameters, the <u>overhang ratio</u>, X/H, and the <u>separation ratio</u>, Y/H. The relative energy savings, $\Delta Q'$, is calculated as a function of these two parameters.

The analysis method is hour-by-hour computer simulation using typical meteorological year (TMY) data for selected cities. The simulation model has heating and cooling thermostat setpoints at 18.3°C (65°F) and 23.9°C (75°F), respectively. The heating and cooling loads are calculated as the auxiliary energy flows required to maintain the space temperature between these two setpoints. The model accounts for solar gains through an equatorial-facing, double-glazed aperture. The incident solar radiation is calculated from the TMY total horizontal and direct normal solar radiation data assuming isotropically diffuse sky radiation and ground reflection with a ground reflectance of 0.3. Losses through the glazing system are calculated in detail. Conduction and infiltration gains and losses through the nonsolar parts of the building envelope are calculated in terms of a single building load coefficient (BLC, kJ/°C day), the steady-state heat gain or loss through the nonsolar parts of the building envelope per unit of indoor-outdoor temperature difference. There are no internal sources.

The building is characterized by its load collector ratio (LCR, kJ/°C day m^2), that is, the ratio of the BLC to the collection area. The collection area is defined as the vertical projection of the net glazed aperture area (m^2).

In summary, the performance of a shading overhang is calculated in terms of the relative energy savings ($\Delta Q'$) as a function of the overhang and separation ratios (X/H and Y/H), and the parameters COP and LCR. The calculation is specific to a particular location as characterized by its TMY and to the characteristics of the passive solar heating system.

3. THE RESULTS

Results are presented for the case of a water wall type of passive solar heating system assuming a water wall thickness of 15.2 cm (6 in.), or a heat capacity of 354 kJ/m^2 of collection area (31.2 Btu/ft^2). The wall is double glazed and has a solar absorptance of 0.9.

Figures 2 through 9 show the results in the form of contour plots where the independent variables are the overhang and separation ratios, and the contours are lines of constant energy savings. The values that label the contours are the relative annual energy savings ($\Delta Q'$), in units MJ/m^2 of glazed aperture ($MJ = 10^6$ J). Each figure corresponds to a particular city, LCR, and COP, and is a summary of 26 annual energy savings calculations in which the overhang and separation ratios are incremented independently in the range 0 to 1. Interpolation is done between the calculated points to plot smooth contours.

Several features of overhang performance are evident from the plots:

Cases exist where an overhang yields no energy savings at all, where, on the contrary, an overhang always yields an energy penalty. See, for example, Figs. 3 and 9. Such cases occur when the COP is sufficiently large that the winter heating penalty of an overhang cannot be compensated for by cooling load reduction. This can happen for relatively small COPs in locations with cold winters and mild summers or for locations with hot summers if the COP is relatively large due to the use of energy-efficient cooling equipment, such as evaporative coolers, where this is possible

In cases where an overhang <u>can</u> yield energy savings, there is a broad region of relative optimum values of overhang and separation ratio pairs where the energy savings is near its maximum within the limits of the plots. The optima are characterized by a linear region on the overhang ratio-separation ratio plane, so that a relationship of the form

$$Y/H = b_0 + b_1 X/H \quad , \tag{5}$$

where b_0 and b_1 are constants for a given building and location, accurately characterizes the preferred relationship between the overhang and separation ratios.

There is no strictly optimum overhang configuration. Rather, the energy savings continues to increase as the overhang and separation ratios increase along the line of their local optima (Eq. 5), at least within the limits of practical overhang sizes. But the majority of the benefit is typically reached by overhang ratios of 0.3 or 0.4,

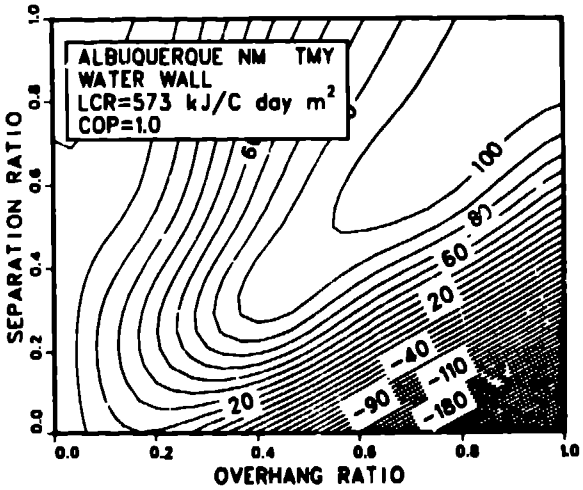

Fig. 2.

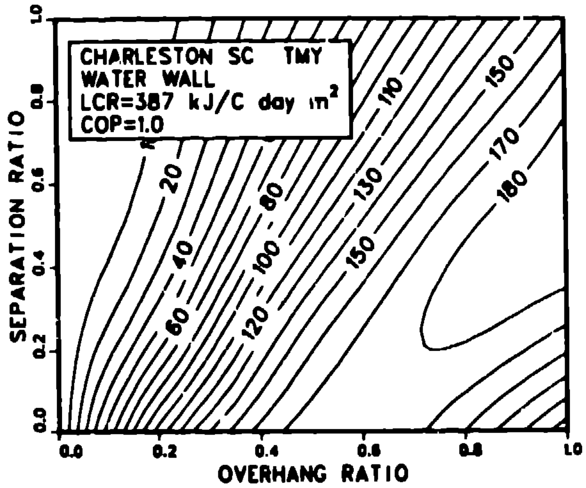

Fig. 5.

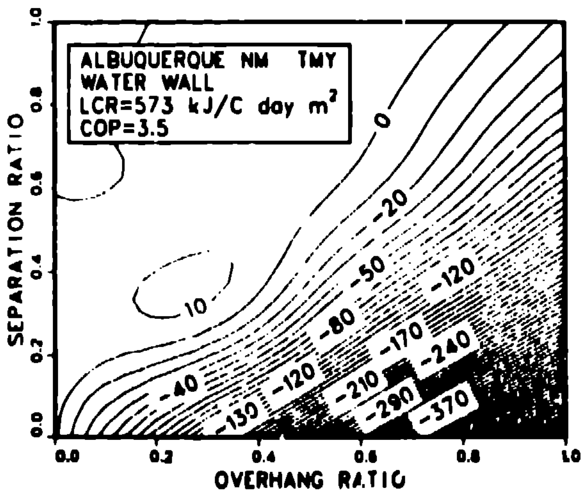

Fig. 3.

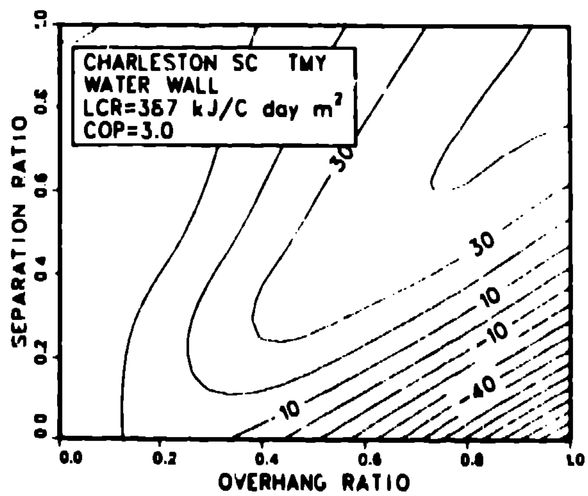

Fig. 6.

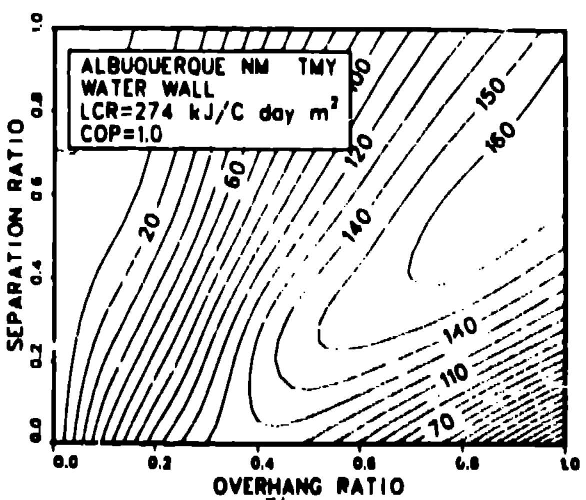

Fig. 4.

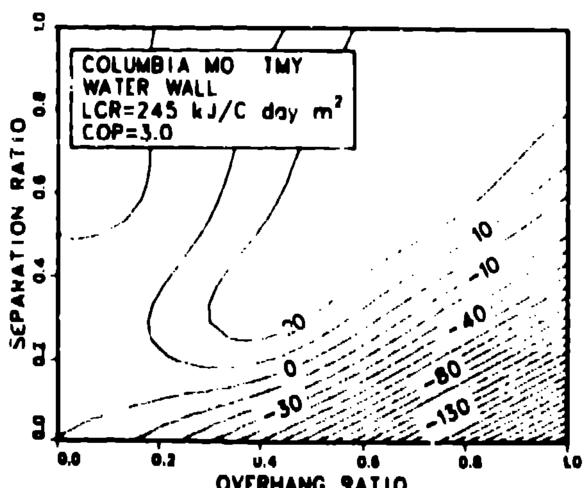

Fig. 7.

Fig. 2-7. Curves of constant relative annual energy savings (MJ/m² of solar aperture, MJ = 10^6 J) achieved by a shading overhang versus the overhang and separation ratios.

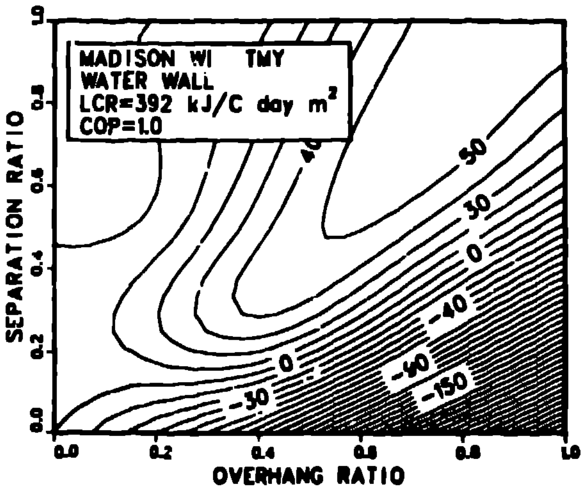

Fig. 8

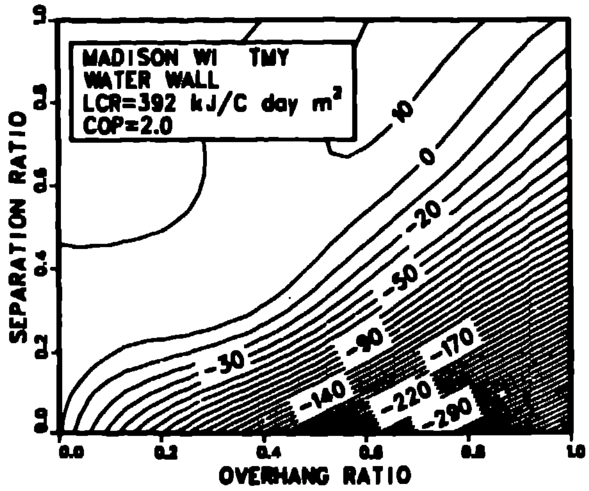

Fig. 9.

Figs. 8-9. Curves of constant relative annual energy savings (MJ/m^2 of solar aperture, MJ = 10^6 J) achieved by a shading overhang versus the overhang and separation ratios.

and rather little additional energy savings is available beyond that.

The dire energy consequences of a separation ratio too small for a given overhang ratio are evident from the precipitous fall in energy savings at the lower right of the plots. This phenomenon occurs because an insufficient separation ratio causes some upper portion of the window to be shaded from direct radiation during part or all of the heating season. The shaded portion is then a net energy loser. Although obvious, this point bears emphasis because it is so often ' :d in practice.

4. CONCLUSIONS

The calculated performances show that the optimum overhang characteristics depend strongly on all of the features that distinguish the various cases: the location, the building LCR, and the COP of the cooling system relative to the auxiliary heating system. The latitude alone is certainly insufficient data from which to determine the overhang configuration. This point is illustrated by Fig. 10 in which are plotted a characteristic of the optimum overhang configuration, b_1, versus the latitude for 73 cases of the type represented by Figs. 2 through 9. The quantity b_1 is the slope of the line of local overhang optima (Eq. 5). No correlation is evident. Other attempts to correlate the optimum overhang characteristics with the latitude were similarly unsuccessful.

It is interesting, and disappointing, that a common and traditional design feature such as the fixed, horizontal overhang is not subject to a simple design rule of thumb.

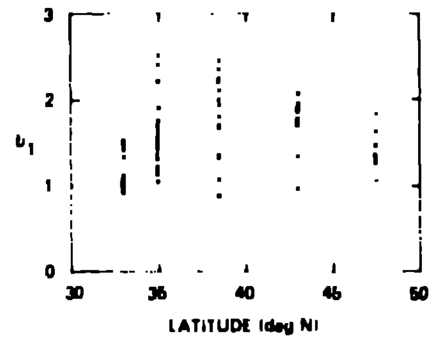

Fig. 10. Values of b_1 (see text for definition) versus latitude.

Instead, it is likely that a useful design tool will necessarily involve a rather complex relationship between several characteristics of the building and its site. Such a tool may turn out to resemble the monthly SLR method extended to apply to both heating and cooling. Meanwhile, an assortment of plots such as those in Figs. 2 through 9, prepared for various regions, LCRs, and COPs, can provide some guidance in overhang sizing.

5. REFERENCES

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